MOTION IMAGERY STANDARDS BOARD

STANDARD	**MISB ST 1603**
Time Transfer Local Set and Enhanced Precision Time Stamp Metadata	**27 October 2016**

1 Scope

This standard defines two metadata constructs: The **Time Transfer Local Set** and the **Enhanced Precision Time Stamp**. The **Time Transfer Local Set** defines metadata elements to validate and correct timestamps. In addition, a leap second offset is included to adjust an International Atomic Time (TAI) timestamp to Universal Coordinated Time (UTC).

The **Enhanced Precision Time Stamp** is a KLV pack construct consisting of a timestamp counter specified to a resolution of 1 nanosecond (i.e. a nanosecond clock), and the Time Transfer Local Set. The Enhanced Precision Time Stamp provides finer temporal resolution than the microsecond Precision Time Stamp specified in MISB ST 0603 [1].

2 References

[1] MISB ST 0603.2 Common Time Reference for Digital Motion Imagery Using Coordinated Universal Time (UTC), Feb 2014

[2] MISB MISP-2017.1: Motion Imagery Handbook, Oct 2016

[3] MISB ST 0807.18 MISB KLV Metadata Dictionary, Oct 2016

[4] Assistant Secretary of Defense for Command, Control, Communications and Intelligence Global Positioning Standard Positioning Service Performance Standard 4th Ed, Sept 2008

[5] IEEE Standard 1588-2002.1 IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems, 2002

[6] IRIG Standard 200-04 Telecommunications and Timing Group/Range Commanders Council, Sep 2004

[7] IEEE Standard 1588-2008.2 IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems, 2008

[8] IETF RFC 1305 Ver. 3 .3 Network Time Protocol, 1992

[9] IETF RFC 5905 Ver. 4 Network Time Protocol, Jun 2010

3 Acronyms

CRC	Cyclic Redundancy Check

GPS	Global Positioning System
IRIG	Inter-range Instrumentation Group
KLV	Key Length Value
NTP	Network Time Protocol
PPS	Pulse Per Second
PTP	Precision Time Protocol
SI	International System (of units)
TAI	International Atomic Time
UTC	Universal Coordinated Time

4 Revision History

Revision	Date	Summary of Changes
ST 1603	10/27/2016	Initial Release

5 Introduction

The Precision Time Stamp specified in MISB ST 0603 is an implementation of the MISP Time System defined in the Motion Imagery Handbook [2]. The Precision Time Stamp represents a count of the number of microseconds since the MISP Epoch. The MISP Time System is a "Level 3" time system exemplifying the following characteristics:

1. Total Order of data
2. Relative Differencing
3. Absolute Time reference

Locally, the Precision Time Stamp derives its count using an internal clock, which references an external clock source, such as a Global Positioning System (GPS) receiver, Inter-range Instrumentation Group (IRIG) system, or a Precision Time Protocol (PTP) device. A group of highly accurate atomic clocks form the foundation of time distribution, where a time signal – called the reference clock, is distributed to one of more local clocks – called a receptor clock. Time Transfer is the process of communicating time from the reference clock to a receptor clock.

Figure 1 illustrates a time transfer system where the goal is to transfer the time established by a referenced atomic clock time to ultimately a receptor clock used by a sensor.

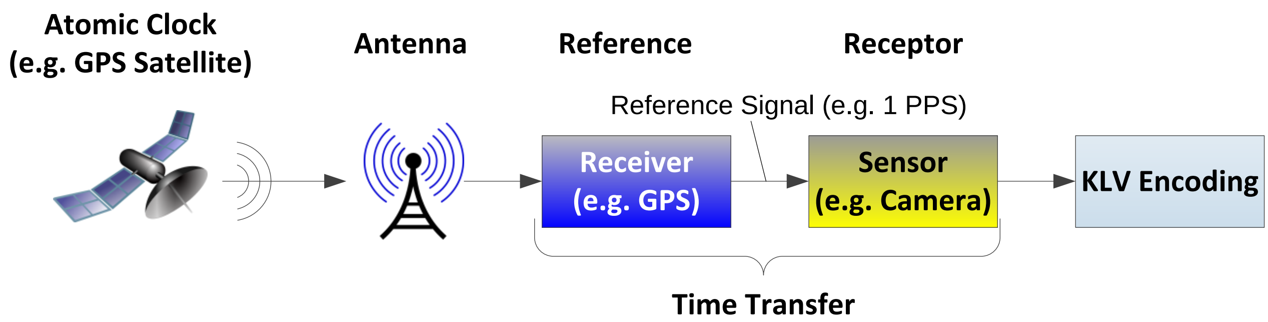

Figure 1: Time Transfer System

There are two time-transfer operations occurring in Figure 1: the first is the atomic clock to a receiver; the second is the receiver to a sensor. This standard provides metadata to qualify the time transfer process between a receiver (Reference) and a sensor (Receptor). This standard does not address the time transfer process between an atomic clock and a receiver, which being integral to the receiver electronics is difficult to ascertain. In Figure 1, with the Receiver synchronized to the Atomic Clock, the Receiver now becomes the Reference Signal source for the Sensor's local clock. The Receiver produces both a time value, and a Reference Signal. The Reference Signal is a highly accurate pulse aligned to the exact time when an SI second (or fraction thereof) occurs.

In practical application, continuous Time Transfer is not 100% guaranteed. For instance, a receptor clock may temporarily lose its ability to report time at a Level 3, whereby timestamps might be produced at a Level 0 instead. By tracking the Time Transfer process, and reporting this information as metadata, the reported time can be corrected to Level 3 in post processing. Furthermore, using a corrective set of rules the reported time during Time Transfer loss can guarantee at least a Level 1 timestamp. To perform correction, and optionally guarantee a minimum of Level 1 performance, this standard defines the Time Transfer Local Set. Consult the Motion Imagery Handbook for details on the method to adjust a receptor clock.

To achieve Level 3, the Precision Time Stamp is the count of SI microseconds since the MISP Epoch without adjustment for leap seconds. The Precision Time Stamp is not equal to UTC, so when reporting time in UTC, a leap second adjustment must be made. The International Earth Rotation and Reference Systems Service (IERS) can update leap second information over any 6-month period, so leap second information is included in the Time Transfer Local Set to track the current adjustment value. Some receivers (e.g. GPS) provide leap second information along with their timing signals.

The Precision Time Stamp has a resolution of microseconds (1e-6 seconds), which is sufficient for most applications; however, some applications require temporal accuracy in the sub-microsecond range. The Enhanced Precision Time Stamp defines a count specified to nanosecond (1e-9 seconds) resolution, and additionally provides Time Transfer information within one KLV pack structure.

6 Time Transfer Local Set

The purpose of the Time Transfer Local Set is to qualify the relationship between a receptor clock and its reference clock with status information. The reference clock is a highly accurate reference signal, which a receptor can synchronize its clock. However, if the reference signal is disrupted or lost, the receptor clock "free-wheels" (i.e. drifts) slowly diverging from the reference clock. When the reference signal is re-acquired, there is likely a temporal difference between the two clocks which requires a correction. There are two methods supported in the Time Transfer Local Set to correct this difference: Jam Correction and Slew Correction.

Jam Correction forces an abrupt change to a receptor's clock report time to the latest reported time of the reference clock. If the receptor clock is free-wheeling faster than the reference clock, the reported time forces a negative jump (i.e. backward) in time creating a negative timing discontinuity. Such discontinuities change the system to Level 0 and complicates downstream processing.

Slew Correction slows down the receptor clock allowing the reference clock to "catch up". During this period of slewing, the difference between the reported time (receptor clock) and the reference time (reference clock) is included as metadata; this metadata enables an application to correct time instantaneously, if needed. Proper initialization in Slew Correction ensures monotonicity. When used, Slew Correction maintains a minimum of a Level 1 Timing System, insuring Total Ordering. Section 8 provides the rules for Slew Correction.

The Time Transfer Local Set applies to the timestamp defined in the metadata set it appears; to generalize, this timestamp is called the *parent time*. For example, within a MISB ST 0601 UAS Datalink Local Set, the Time Transfer Local Set applies to the Precision Time Stamp value (Tag 2), which in this case is the parent time. Every instance of a parent timestamp within a metadata set is a *time report*. Certain Time Transfer metadata elements are required at a minimum periodicity, while other elements are included under certain conditions, or on a less-frequent basis.

The Time Transfer Local Set is always embedded within another metadata set or group. For this reason, the Time Transfer Local Set does not include a CRC value, because the metadata set or group containing the parent time should already provide CRC validation.

The Time Transfer Local Set 16-Byte Universal Label is registered in MISB ST 0807 [3] as:

06.0E.2B.34.02.0B.01.01.0E.01.03.02.02.00.00.00 (CRC 43211)

6.1 Local Set Elements

The Time Transfer Local Set elements are listed in Table 1, which has the following column designations:

- **Tag ID** is the Local Set tag number for the element in the Time Transfer Local Set.
- **Element Name** is the name of the element.
- **Key** is the SMPTE KLV registry key for the element registered in MISB ST 0807.
- **Section** is the section number in this document providing details for the element.

- **Type** indicates the data type of the element.
- **Usage** is the reporting frequency (i.e. once per 30 seconds), or the conditions for which it is reported.

Table 1: Time Transfer Local Set

Local Set Key				Name		
06.0E.2B.34.02.0B.01.01.0E.01.03.02.02.00.00.00 (CRC 43211)				Time Transfer Local Set		
Tag	**Element Name**	**Key Value (hex)**	**Section**	**Type[1]**	**Units**	**Usage**
1	Document Version	06.0E.2B.34.01.01.01.01.0E.01.02.05.05.00.00.00 (CRC 56368)	6.2.1	uint	N/A	Use at least once per 30 Seconds
2	UTC Leap Second Offset	06.0E.2B.34.01.01.01.01.0E.01.01.02.0A.00.00.00 (CRC 41450)	6.2.2	int	Seconds	Use at least once per 30 Seconds
3	Time Transfer Parameters	06.0E.2B.34.01.01.01.01.0E.01.01.02.0A.01.00.00 (CRC 38618)	6.2.3	uint	N/A	Use at least once per 30 Seconds
4	Synchronization Pulse Frequency	06.0E.2B.34.01.01.01.01.0E.01.01.02.0A.02.00.00 (CRC 53130)	6.2.4	float	Hz	Use at least once per 30 Seconds
5	Unlock Time	06.0E.2B.34.01.01.01.01.0E.01.01.02.0A.03.00.00 (CRC 63674)	6.2.5	uint	See Section	Use only when lost lock
6	Last Synchronization Difference	06.0E.2B.34.01.01.01.01.0E.01.01.02.0A.04.00.00 (CRC 32042)	6.2.6	uint	See Section	Use only when providing Slew Correction
7	Drift Rate	06.0E.2B.34.01.01.01.01.0E.01.01.02.0A.05.00.00 (CRC 18970)	6.2.7	float	μs/s	Use at least once per 30 Seconds
8	Signal Source Delay	06.0E.2B.34.01.01.01.01.0E.01.01.02.0A.06.00.00 (CRC 4938)	6.2.8	uint	ns	Use at least once per 30 Seconds
9	Receptor Clock Uncertainty	06.0E.2B.34.01.01.01.01.0E.01.01.02.0A.07.00.00 (CRC 9338)	6.2.9	uint	See Section	Use at least once per 30 Seconds

[1]Note on Lengths: Lengths for all types in the Time Transfer Local Set are computed by the size of the value. For example, if a uint value is less than 255 then only one byte is needed. See the Motion Imagery Handbook [2] for more information on data types and lengths.

6.2 Element Details

6.2.1 Document Version

The Document Version identifies the version of MISB ST 1603 for the Time Transfer Local Set. The value is set to the minor version of the document; for example, ST 1603.1 would have a value of 1. The Document Version is present in the stream at least once every thirty seconds.

Requirement	
ST 1603-01	The Document Version shall be included in the Time Transfer Local Set at least once every 30 seconds.

6.2.2 UTC Leap Second Offset

The UTC Leap Second Offset is an integer number of SI seconds used to convert a timestamp to Universal Coordinated Time (UTC), and accounts for leap seconds since the MISP Epoch as defined in the Motion Imagery Handbook. For GPS systems, the leap second difference between the MISP Epoch and the GPS Epoch is 19-8=11. When GPS reports a leap second offset (relative to the GPS Epoch) the value of 11 is added to make it relative to MISP Epoch.

The UTC Leap Second Offset is required to be included in a Motion Imagery stream along with time reports; however, this value does not need to be present with every time report. The UTC Leap Second Offset value usually changes at most once a year. During regular operation, the UTC Leap Second Offset is delivered in the Time Transfer Local Set as infrequently as once every 30 seconds.

Some systems, such as GPS, announce months in advance when the next leap second will be added. When a leap second change is going to occur within the next 30 seconds, the UTC Leap Second Offset is included with every reported time. During and after the leap second change, the UTC Leap Second Offset report continues to be included with every reported time for 30 seconds after the change. After the update, the UTC Leap Second Offset reports at its nominal rate, but no more than 30 seconds apart.

Requirement	
ST 1603-02	The UTC Leap Second Offset shall be included in the Time Transfer Local Set at least once every 30 seconds.

6.2.3 Time Transfer Parameters

Time Transfer Parameters is a binary value combining three items: The Reference Source Status, Correction Method, and Time Transfer Method.

The Time Transfer Parameters value is not required for every time report, but it must appear in a Motion Imagery stream at least once every 30 seconds.

	Requirement
ST 1603-03	The Time Transfer Parameters shall be included in the Time Transfer Local Set at least once every 30 seconds.

Figure 2 illustrates the binary format for the Time Transfer Parameters. The Time Transfer Parameters is one-byte long (this could become larger in future versions of this standard). The least two significant bits (i.e. bit 0 and bit 1) indicate the Reference Source (see Section 6.2.3.1); the next two significant bits (i.e. bit 2 and bit 3) indicate the Correction Method (see Section 6.2.3.2); the next four significant bits (bit 4, 5, 6 and 7) indicate the Time Transfer Method (see Section 6.2.3.3).

(msb)			Bits				(lsb)
7	6	5	4	3	2	1	0
Time Transfer Method				Correction Method		Reference Source	

Figure 2: Time Transfer Parameters

When future versions add additional bytes, they will be added as more significant bytes, where the byte shown in Figure 2 will be the Least Significant Byte (LSB).

6.2.3.1 Reference Source

The Reference Source indicates if the reference clock is synchronized to an atomic source (i.e. atomic clock), or not. For example, in normal operations, a GPS synchronizes to satellites, and effectively, an atomic clock. However, if its antenna were broken, the GPS could no longer synchronize to the atomic clock. When the reference clock is synchronized to an atomic source (e.g. TAI or GPS), the Reference Source value is set to two (2); otherwise, it is set to one (1). When the state of the clock is unknown, a value of zero (0) is assigned. Table 2 summarizes the allowed values for the Reference Source.

Table 2: Allowed values for Reference Source

Value	Meaning
0	Reference Source status is unknown
1	Reference Source is not synchronized to an atomic source
2	Reference Source is synchronized to an atomic source
3	Reserved for future use

6.2.3.2 Correction Method

The Correction Method indicates Jam Correction, Slew Correction or Unknown (see Section 8 for details on Correction Method application). Table 3 lists the valid values for the Correction

Method. Unknown indicates either no correction, or a method other than Jam/Slew Correction is applied.

Table 3: Allowed values for Correction Method

Value	Meaning
0	Unknown
1	Jam Correction
2	Slew Correction
3	Reserved for future use

6.2.3.3 Time Transfer Method

The Time Transfer Method indicates the system used to transfer time from a reference clock to a receptor clock. Table 4 lists the valid values for the Time Transfer Method. Many known time reference systems are represented; others will be added in the future if applicable. A value of zero (0) alerts users the reported time has uncertainty in how it was created.

Table 4: Allowed values for Time Transfer Methods

Value	Meaning
0	Unknown Time Transfer Method
1	Global Positioning System (GPS) PPS [4]
2	Precision Time Protocol (PTP) - Version 1 [5]
3	Precision Time Protocol (PTP) – Version 2 [7]
4	Network Time Protocol (NTP) [8]
5	Network Time Protocol (NTP) [9]
6	Inter-range Instrumentation Group (IRIG-A) [6]
7	Inter-range Instrumentation Group (IRIG-B) [6]
8-15	Reserved for future use

6.2.4 Synchronization Pulse Frequency

The Synchronization Pulse Frequency specifies the periodicity of the pulse transmitted by a reference time source. The unit of measure is Pulse per [SI] Second (PPS) or Hertz (Hz). This value is not required, and has a default value of one (1.0 PPS). When this value is provided, it must appear in the stream at least once every 30 seconds.

Requirement	
ST 1603-04	While the Synchronized Pulse Frequency is not equal to one (1.0) Pulse per [SI] Second (PPS), the Synchronized Pulse Frequency shall be included in the Time Transfer Local Set at least once every 30 seconds.

6.2.5 Unlock Time

The Unlock Time is the duration of time since a receptor clock was last locked to the reference clock (see the Motion Imagery Handbook for details). This value is required for every time report during which lock is lost. The default value is zero (0). When the reference and receptor clocks are locked, this value is zero (0), and therefore, does not need to be reported. A non-zero value is an indicator the receptor clock is not locked to the reference clock; this replaces the locked/unlocked bit used in other standards. The units for this measurement are the same as the units of the parent time.

Requirement	
ST 1603-05	While the Unlock Time is greater than zero (0), Unlock Time shall be included in the Time Transfer Local Set.

6.2.6 Last Synchronization Difference

When performing Slew Correction, the Last Synchronization Difference is either the current difference in time between a receptor clock and its reference clock during slewing, or the last known greater-than-zero difference during slewing (see the Motion Imagery Handbook for a description). When using Slew Correction, this value is required every time report its value is greater than zero (0). When the value is zero, it is not included in the Local Set, i.e. the default value is zero (0). The units for this measurement are the same as the units of the parent time.

Requirement	
ST 1603-06	Where using Slew Correction, when the Last Synchronization Difference is greater than zero, the Last Synchronization Difference shall be included in the Time Transfer Local Set.

6.2.7 Drift Rate

The Drift Rate is the known maximum drift rate of the receptor clock when freewheeling. When this value is provided, it must appear in the stream at least once every 30 seconds. When this value is not included in the stream, it means the drift rate is unknown, i.e. there is not a default value. This value can be a positive or negative floating-point value, and the units are in microseconds per second (μs/s).

When the Drift Rate is included in the Time Transfer Local Set, the reported time's uncertainty is usable in real time when the reference source is lost.

Requirement	
ST 1603-07	Where the Drift Rate is included, the Drift Rate shall be included in the Time Transfer Local Set at least once every 30 seconds.

6.2.8 Signal Source Delay

The Signal Source Delay is the estimated or measured latency of the time signal from the reference clock to the receptor clock. For example, on-board a ship a GPS antenna could be 200 meters from a receiver, where the signal incurs a non-zero latency. When this value is provided, it must appear in the stream at least once every 30 seconds. When this value is not included in the stream, the default delay is zero (0). The units for this measurement are nanoseconds.

Requirement	
ST 1603-08	Where the Signal Source Delay is greater than zero (0), it shall be included in the Time Transfer Local Set at least once every 30 seconds.

6.2.9 Receptor Clock Uncertainty

The Receptor Clock Uncertainty is the estimated error of the receptor clock (i.e. standard deviation of the measured time, see [2]). When this value is provided, it must appear in the stream at least once every 30 seconds. When this value is not included in the stream, it means the Receptor Clock Uncertainty is unknown. The units for this measurement are the same as the units of the parent time.

Requirement	
ST 1603-09	Where the Receptor Clock Uncertainty is included, it shall be included in the Time Transfer Local Set at least once every 30 seconds.

7 Enhanced Precision Time Stamp

The Enhanced Precision Time Stamp is a KLV construct composed of a two-element truncation pack. The first element is a 64-bit unsigned integer representing a nanosecond time counter measured from the MISP Epoch as defined in MISB ST 0603. The second element is the value portion of the Time Transfer Local Set. A truncation pack saves bandwidth and co-joins the time transfer metadata to be directly associated with its parent time within the same KLV group. Figure 3 illustrates the two-value pack layout.

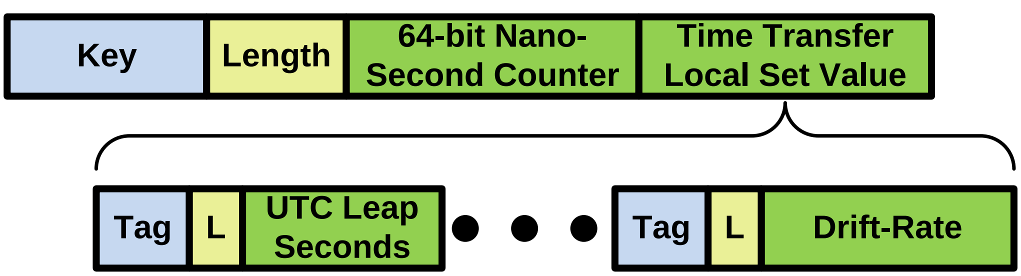

Figure 3: Illustration of Extended Precision Time Stamp KLV Pack

The KLV Key for the Enhanced Precision Time Stamp Pack is registered in MISB ST 0807 as:

06.0E.2B.34.02.05.01.01.0E.01.03.02.09.00.00.00 (CRC 58798)

The 64-bit Nano-Second Counter represents a sampled and quantized time value of the MISP Time System. The 64-bit Nano-Second Counter is defined to have the following properties:

1. Represented as a 64-bit unsigned integer (UINT64).
2. Specified to a resolution of 1 nanosecond. Sub-nanosecond measurements are truncated to the nearest nanosecond.
3. Assigned the following KLV key as registered in MISB ST 0807:

06.0E.2B.34.01.01.01.01.0E.01.01.02.0A.08.00.00 (CRC 2123)

Requirement	
ST 1603-10	The 64-bit Nano-Second Counter shall represent a value of the MISP Time System truncated to the nearest nanosecond.

This 64-bit nanosecond counter follows the same rules as the Precision Time Stamp defined in MISB ST 0603, but instead of counting microseconds, it counts nanoseconds. The maximum value or roll over is:

$$\frac{2^{64}-1}{86400 * 365.24 * 1\mathrm{E}9} = \frac{18{,}446{,}744{,}073{,}709{,}551{,}615}{31{,}556{,}736{,}000{,}000{,}000} \approx 584\ years$$

8 Clock Corrections

As discussed in Section 6, there are two methods for correcting a clock value when lock is re-acquired: Jam Correction and Slew Correction. Jam Correction allows a receptors clock value to change negatively, so it matches the receiver’s clock. Slew Correction prevents the time value from changing negatively by slowing incrementing the receptors clock while the receiver’s clock catches up.

Implementing Jam Correction does not require any special metadata in the Time Transfer Local Set.

Implementing Slew Correction requires the use of the Last Synchronization Difference (Section 6.2.6), and some additional requirements on the receptor clock. With Slew Correction, the time value must always increase, so during power-up or initialization (before the first reference lock) the clock value must provide a time that is earlier than the current time. Starting devices using a timestamp value of zero ensures a positive jump when systems are initializing prior to synchronization to a reference clock.

Requirement(s)	
ST 1603-11	Where using Slew Correction, time values shall be monotonically increasing.
ST 1603-12	Where using Slew Correction, the time values before the first reference clock lock shall start at zero (0) and increment at the receptor clocks rate.